

Measuring GALILEO's Channel – The Land Mobile Satellite Channel

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1. Abstract

One leading point in the choice of the signal format for the Galileo System is the multipath transmission channel. Studies concerning the signal structure (e.g. ESA Signal Design Study) 1 had clearly shown that the synchronisation performance of a specific signal strongly depends on the reflections in the environment. Especially short delayed reflections significantly decrease the performance of the receiver. The positioning error becomes even worse if these reflections are strong and slowly varying over time, which is predominant in pedestrian applications. Although narrowband channels like GSM (COST 207) 2 or UMTS have been measured in the past, it became necessary to analyse the wideband navigation channel to minimise multipath effects in future highly accurate receivers. For these reasons the channel from the satellite to a receiver in critical urban and suburban scenarios was measured by a team of research scientists in autumn 2002. This paper will present first preliminary statements and conclusions for typical land mobile applications.

2. Channel measurement

At the time of the measurements the satellites were not yet in orbit – a simulation was needed. The satellite was simulated by a Zeppelin NT operating at distances of up to 4000 meters from the receiver. A special measurement signal with 10W EIRP and a bandwidth of 100 MHz was transmitted. The transmitted signal had a rectangular shaped line spectrum consisting of several hundred single carriers. This guaranteed a time resolution of 10 ns for the channel impulse response, this very high resolution that is necessary for the planned wideband services of Galileo using BOC signal structures. By applying an ESPRIT ("Estimation of Signal Parameters via Rotational Invariance

Techniques") based super resolution algorithm, the time resolution for the final model will be increased to 1 ns.

To achieve this high time resolution specially assembled rubidium clocks with an Allan variance of 10^{-11} seconds over an integration time of 1 second were used as references for the measurement devices.

For the accurate positioning of the Zeppelin the aircraft was filmed a camera station on the ground which was situated directly beyond the aircraft (see Figure 1). The image of the camera was transmitted via a wireless radio link to a monitor in the aircraft and allowed the pilot to control his continuing keeping of the required position. During the measurement the position of the Zeppelin was successfully kept within 30 meters distance to the ideal position.

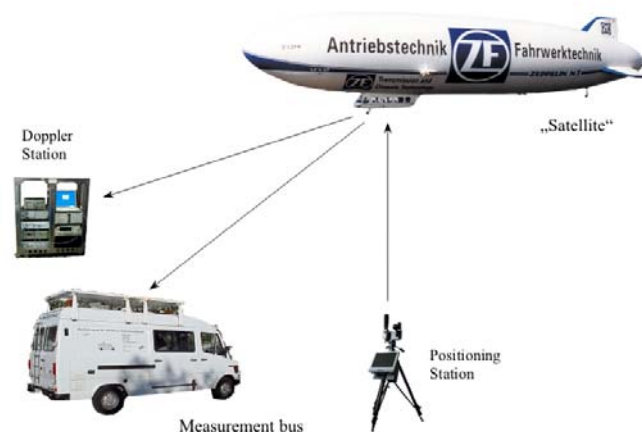


Figure 1: Measurement setup

A measurement vehicle had been equipped with the channel sounder receiver, wheel sensors, laser gyros, audio and video system, data recording and GPS sensors and was used on all measurements. During the campaign 60 scenarios each lasting from 10 to 20 minutes were measured. For the land mobile car channel the focus was on:

- Urban channels (Large city – Munich including a drive along a motorway)
- Suburban channels (Small town – Fürstenfeldbruck)
- Rural channels (Motorway and country roads)

An antenna showing the characteristics of a navigation system receiver antenna was used throughout the measurements to guarantee a realistic modelling.

3. Urban Channel - Large City



Figure 2: Measurement Area "Lindwurmstrasse" in Munich

Figure 3 shows the car track in the "Lindwurmstrasse" area in Munich (see Figure 2). This road is one of the main roads of the capital of the German federal state of Bavaria. The track was followed by narrow roads, street canyons and large squares. For this low elevation the visibility of the satellite is naturally quite low as well. In comparison to a visible satellite in the zenith the power is attenuated about -30 dB. In some areas during the measurement the power comes up to about -20 dB. When the satellite is at this low elevation very long echoes are occurring. It is very typical for a situation like this in reality that the car is driving towards a reflector (buildings etc.) so that the reflection comes closer and closer to the shortest path and finally matches it. In Figure 4 multiple reflection can be seen. The reason for this situation was an urban canyon where most likely the incoming wave bounced several times.

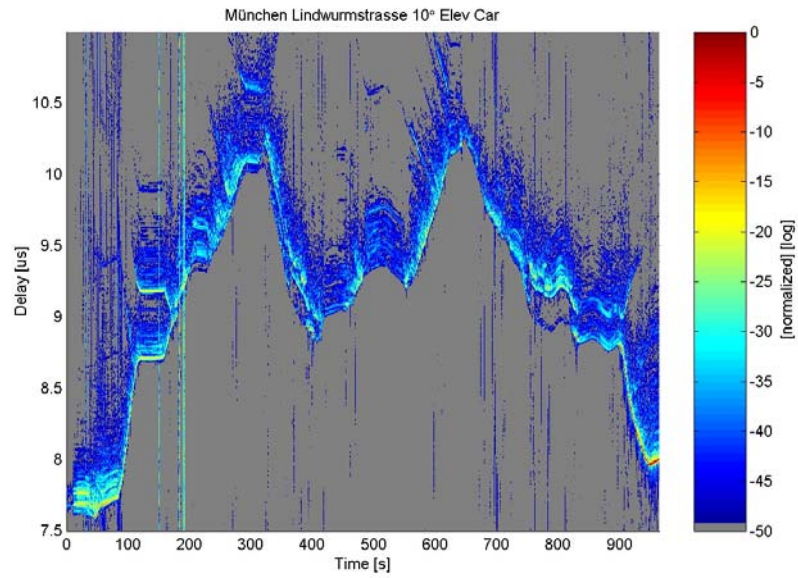


Figure 3: Urban car channel, Munich 10° elevation

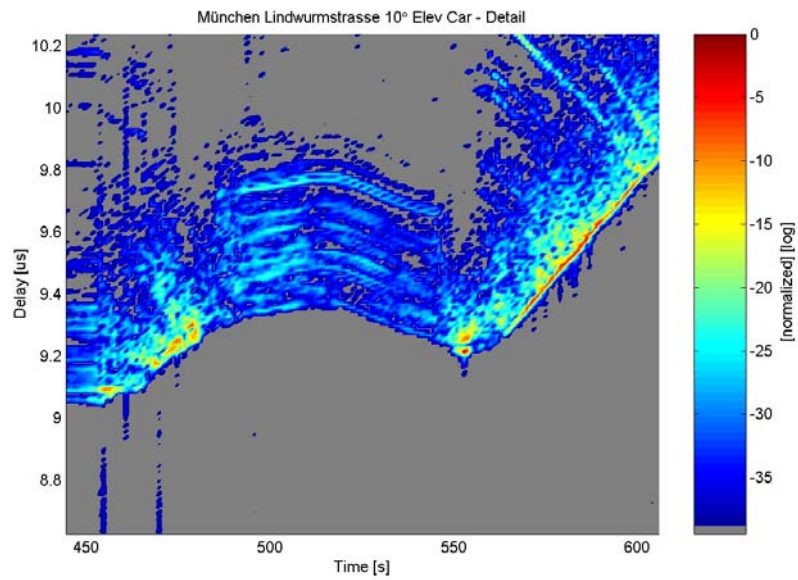


Figure 4: Urban car channel, Munich, 10° elevation – Detail from **Figure 3**

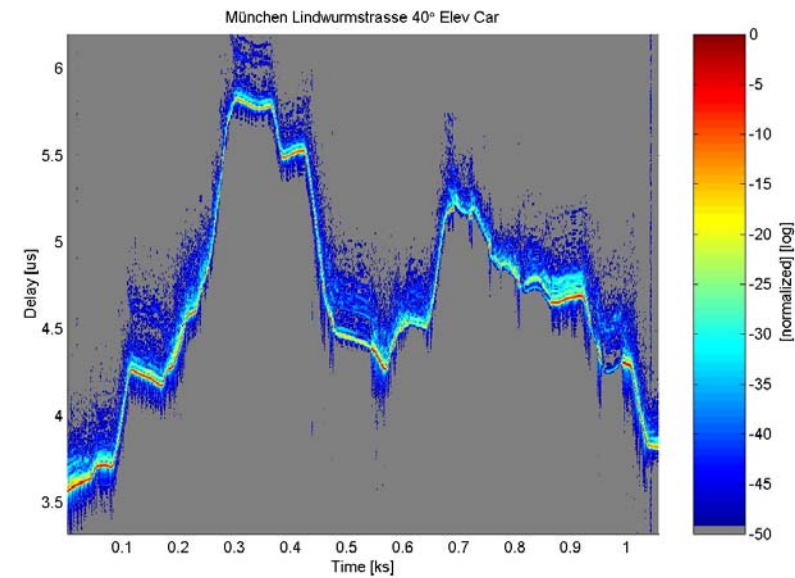


Figure 5: Urban car channel, Munich, 40° elevation

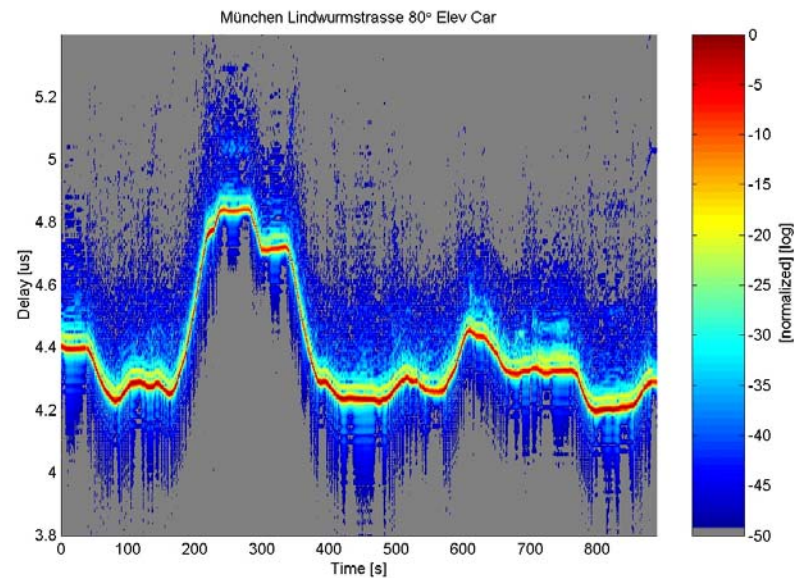


Figure 6: Urban car channel, Munich, 80° elevation

Figure 5 shows the same measurement at 40 degrees elevation. In this situation the visibility increases dramatically. The tendency for long echoes is reduced. Unfortunately another characteristic comes up: The “building echo”. When the incoming ray is arriving at an azimuth from the side it is very likely that an echo occurs with a delay matching the street width (best to be seen between 120 and 180 s). The power of this reflection is quite high and reaches values around -15 to -20 dB. If the incoming ray is arriving from the front the echo tends to be shorter (best to be seen at 440-450 s). Figure 6 shows the same track with the Zeppelin at 80 degrees elevation. There the visibility is very high. The echoes tend to be short and strong. Again the mentioned dependency on the azimuth can be seen: If the ray is coming from the front the echo delay is much shorter as if it comes from the side.

4. Urban City – Small Town

The following measurements have been performed in the small town of Fürstenfeldbruck near Munich. Figure 7 gives an impression of the measurement area. In comparison to the city of Munich the buildings of Fürstenfeldbruck are significantly lower (usually only three floors) and the streets are wider.



Figure 7: City of Fürstenfeldbruck

Similar to the effects we described for the Munich measurements we can see many approaching reflectors as well as constant delays in streets where the

incoming ray approaches sideways (see Figure 8). But due to lower buildings and wider streets delays are usually larger. Furthermore the more open gaps in the sky lead to a slightly better visibility than in the towncenter in Munich.

Increasing the elevation to 40 degrees improves again the visibility of the satellite. Again an echo in a constant delay appears. It is as well correlated with the width of the street. But again the more open sky becomes important. The received power level is higher than in the presence of urban canyons (see Figure 9).

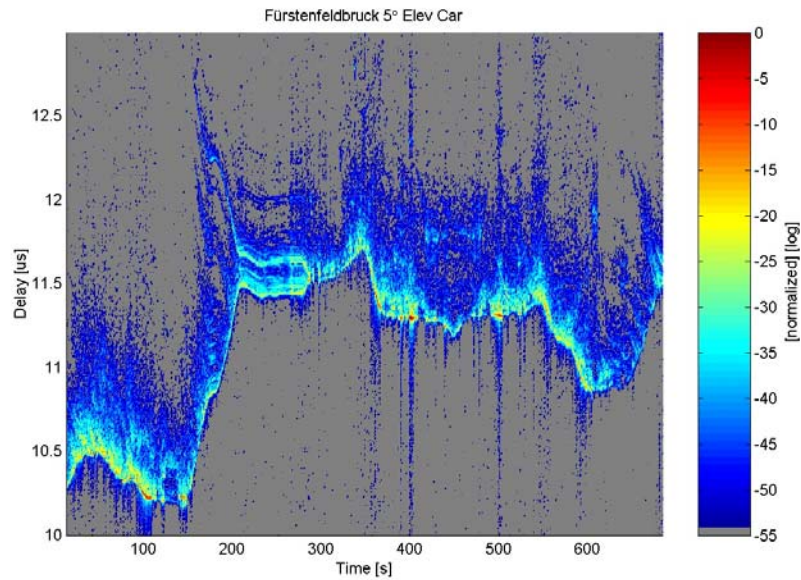


Figure 8: Urban car channel, Fürstenfeldbruck, 5° elevation

Figure 10 depicts the 80 degree measurement in Fürstenfeldbruck. Like in Munich the visibility incenses to its most. The direct path is now nearly always followed by a quite close reflection. This reflection is as well azimuth dependent and has a slightly larger delay due to the wider streets.

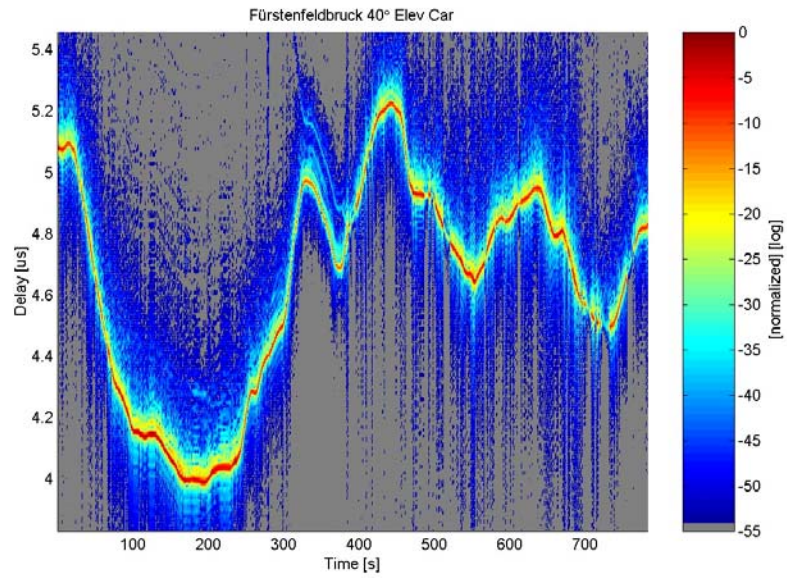


Figure 9: Urban car channel, Fürstenfeldbruck, 40° elevation

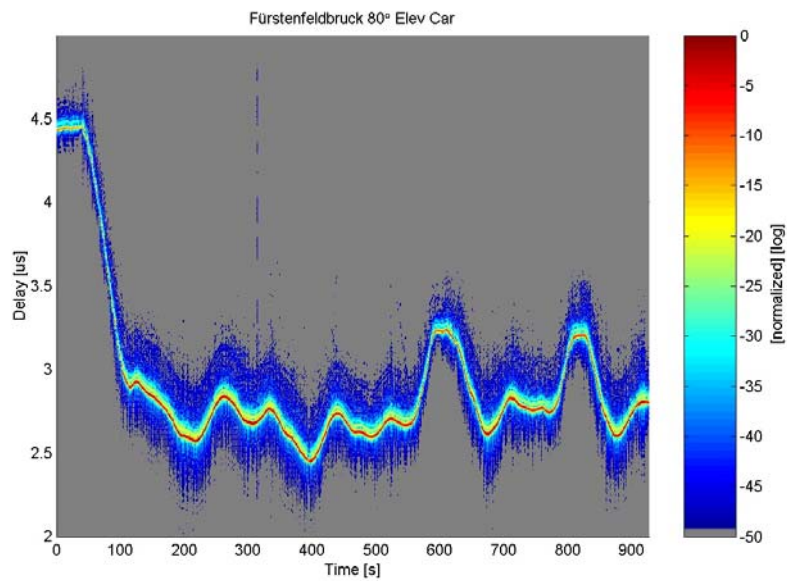


Figure 10: Urban car channel, Fürstenfeldbruck, 80° elevation



Figure 11: Motorway seen from the Zeppelin

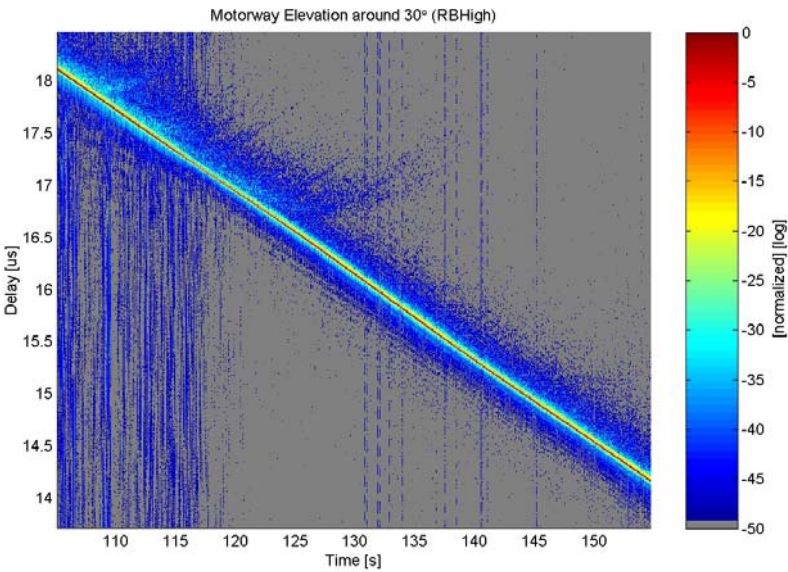


Figure 12: Motorway Elevation 30°

5. Rural Channel – Motorway

Another important application for a navigation system is a drive on the motorway. Therefore this scenario was used for the measurement of different elevations. Figure 11 shows the measurement at an elevation of 30 degrees. On first this channel seems not to be very exciting. On closer view the constant characteristic of the channel seems to be a continuous ground reflection in a certain distance. Other reflections from traffic signs, trees or side walls are unlikely. If they occur their power is very low.

Increasing the elevation towards 80 degrees the channel shows a strong correlation to the low elevation. Only the ground reflection is being moved.

6. Rural Channel – Country road

Other than on the broad motorway without any trees close to the road on a country road the signal is blocked more often. The ground reflection in this application is less sharp and scattered over a wide delay range. Moreover the likelihood for additional reflection from the surrounding seems to be higher on low elevations as seen in Figure 14. Increasing the elevation to 80 degrees (Figure 15) shows in some points a similar characteristic as resulted on the motorway. Again and again these good conditions are interrupted by groups of trees and bushes which results again to a wide scatter of reflections.

7. Conclusion

To evaluate the reflections in urban, suburban and rural environments we performed a measurement campaign in Autumn 2002 was performed. The main outcome is the strong elevation dependency of the channel. For the navigation application it is very important that many short delayed echoes occur. This adverse characteristic of the measured channel must be taken into account in the design phase of new systems and receivers. It could explain the lack of performance in critical situations.

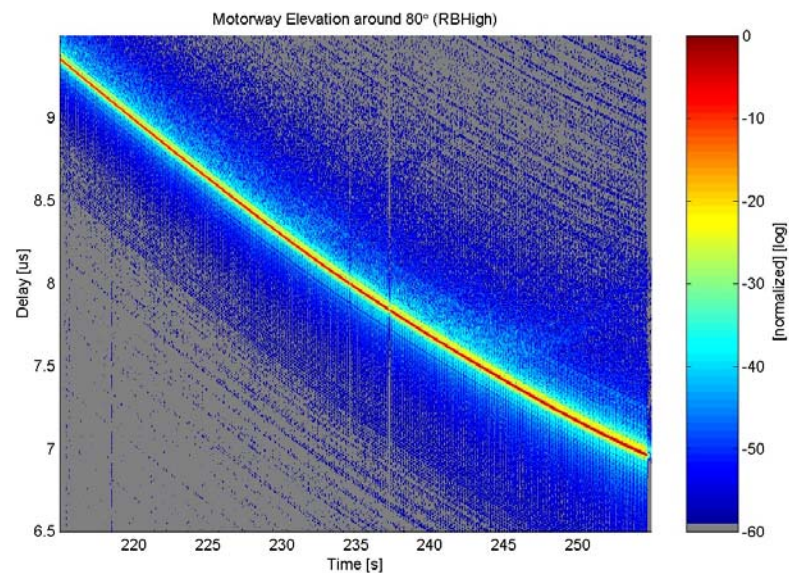


Figure 13: Motorway Elevation 80°

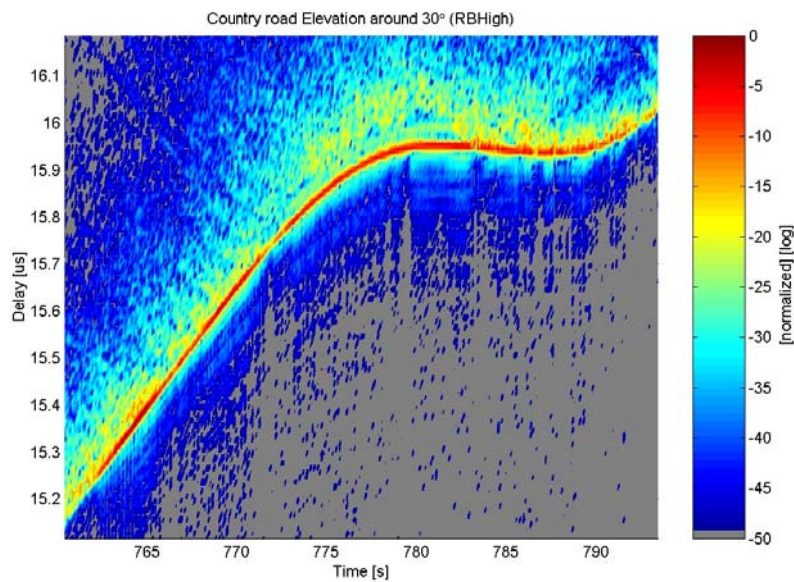


Figure 14: Country road Elevation 30°

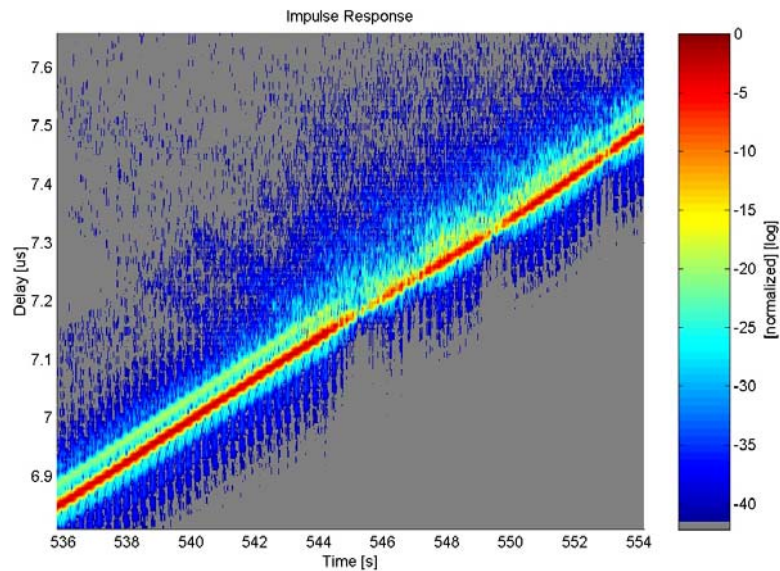


Figure 15: Country road Elevation 80°

References

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